Coevolution of Photosynthesis with the Atmosphere on Extrasolar Worlds: Surface Reflectance Spectra and Atmospheric Exchange

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Although life abounds in hidden places of the Earth, independent of sunlight, only photosynthetic activity produces unequivocal indicators of life that can be detected astronomically. Among these indicators are the vegetation "red edge" and atmospheric oxygen. The "red edge" is the strong spectral reflectance signature of vegetation due to the absorbance of photosynthetic pigments of visible light, contrasting with strong reflectance in the near infrared. The presence of abundant oxygen is the result of the splitting of water molecules during photosynthesis. Could photosynthesis arise on another planet? If so, would it exhibit the same kind of surface spectral signature and the same gaseous products as on Earth? We present a broad survey of reflectance spectra and metabolisms across different types of photosynthetic organisms and review the range of Earth photo-biochemistry adaptations within environmental niches, and growth and survival limits. We hypothesize that the coevolution of photosynthesis with atmospheric composition creates a predictable reflectance spectrum, while climate and resources place bounds on productivity and levels of biosphere-atmosphere exchanges. Transferring Earth's example to extrasolar planets, we present potential "biosignatures" of photosynthetic life around M-stars and their matching atmospheres. Scenarios are presented of: Earth-like oxygenic photosynthesis absorbing low flux densities of visible light; Earth-like anoxygenic photosynthesis absorbing in the near-infrared; and plausible alternative photosynthetic adaptations for M-star environments. Finally, we suggest how the detection of photosynthetic life around M-stars may be targeted in upcoming space telescope missions like the Terrestrial Planet Finder and Darwin.